Forecasting changes in stream flow, temperature, and salmonid populations in Eastern U.S. as a result of climate change

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North Atlantic LCC

USGS
science for a changing world

NALCC project tasks

- Task 1: Hierarchical modeling framework to account for multiple scales and sources of uncertainty in climate change predictions
  - Brook trout models
    - Mechanistic
    - Abundance
    - Occupancy
- Task 2: Statistical environmental models to predict stream flow and temperature based on air temperature and precipitation.
  - Annual stream flow
  - Daily stream temperature
- Task 3: Incorporate climate change forecasts into population persistence models
  - Climate → Environment → Fish
- Task 4: Develop a decision support system for evaluating effects of alternate management strategies in the face of climate change.
  - Web app

Data types

Increasing information

- PIT tag
  - Single-site demographic models
    - Seasonal sensitivity of lambda (population growth)
- Abundance
  - Multiple-site demographic models
    - Sensitivity + basin characteristics
- Presence/absence
  - Occupancy models
    - Effects of long term means + basin characteristics
- Tolerable range
  - Climate envelope models

Data types

Increasing information

- PIT tag
  - Single-site demographic models
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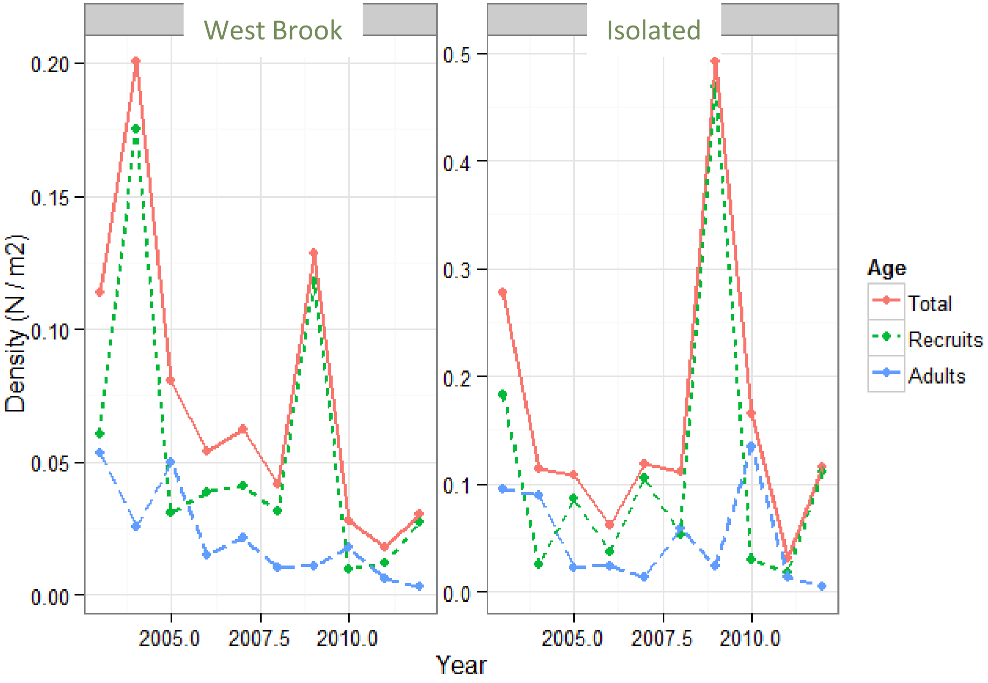
  - Occupancy models
    - Effects of long term means + basin characteristics
- Tolerable range
  - Climate envelope models

Data types

- PIT tag
  - Single-site demographic model
  - Body growth, survival, movement, reproduction
  - Integral projection model
- Abundance
  - Abundance models
- Presence/absence
  - Occupancy models



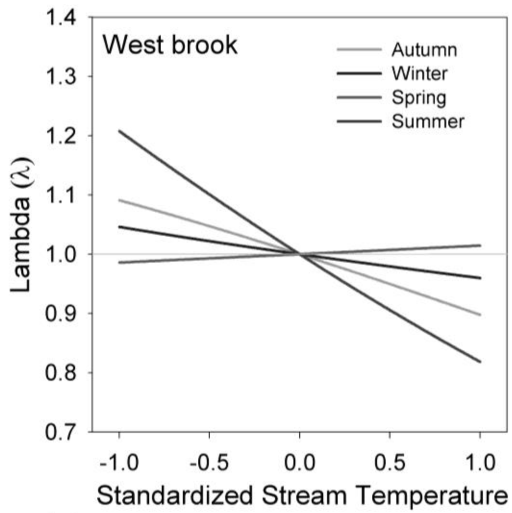
Overview

Stream flow ↓
Stream temperature ↑

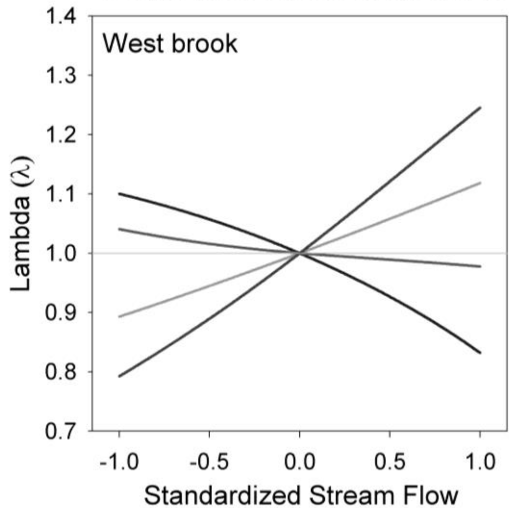
Population size ↓
Body size ↑

- Decrease in flow in autumn and increase in temperature in the summer had the strongest negative effects on changes in abundance
- Compensatory effects of density cannot overcome negative effects of environmental change on abundance
- Abundance changes most sensitive to egg-tagging size stage
  - Focus on small fish
- Body size is increasing in response to lower densities
  - Effects of flow and temperature balance out

Population growth sensitivities



Spring ↔
Winter ↔
Autumn ↓
Summer ↓

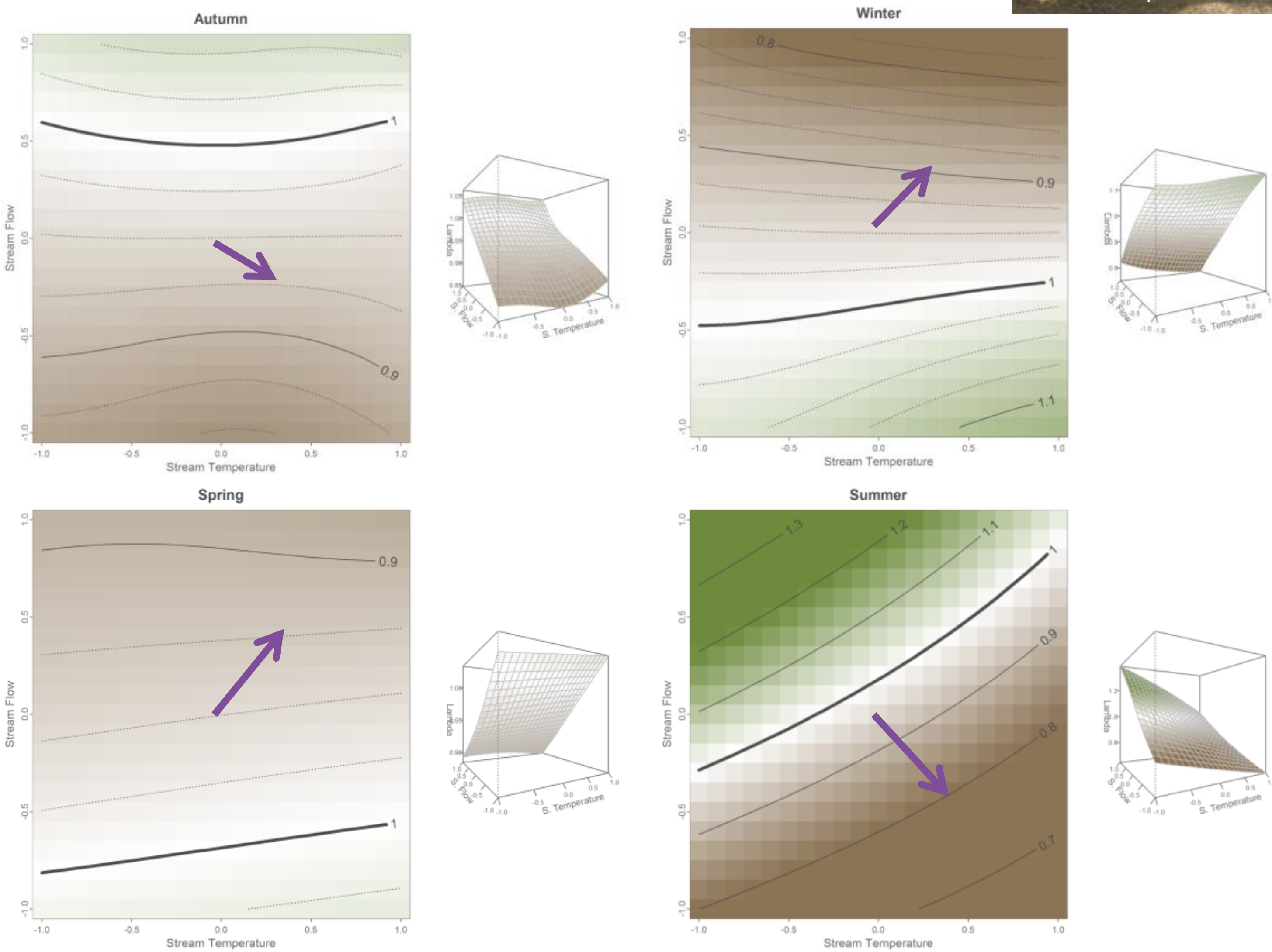


Summer ↑

Autumn ↑
Spring ↔

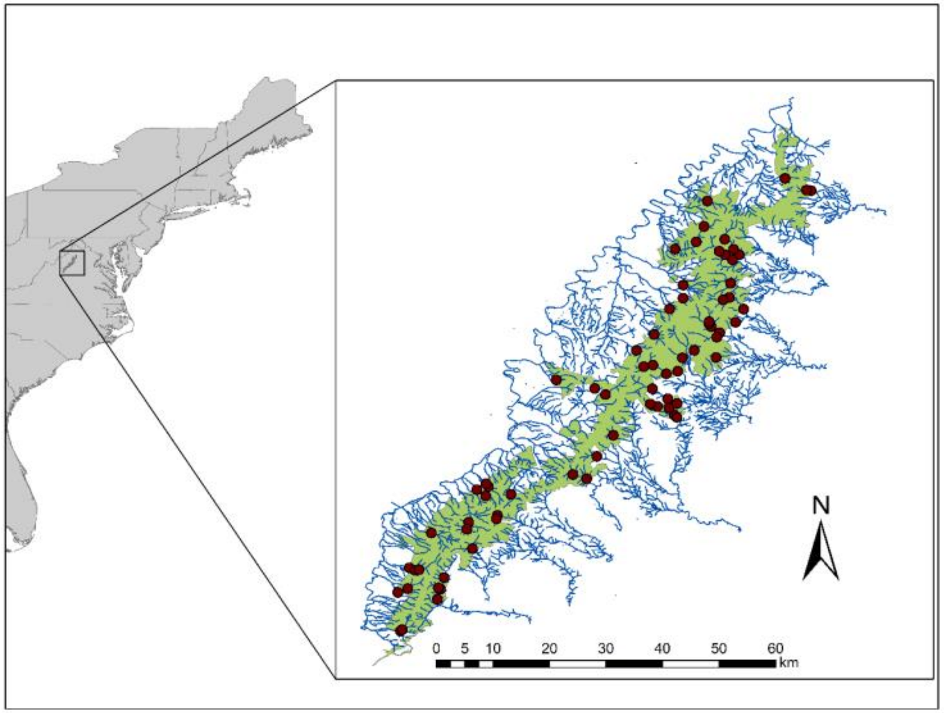
Winter ↓

Lambda response surfaces



Data types

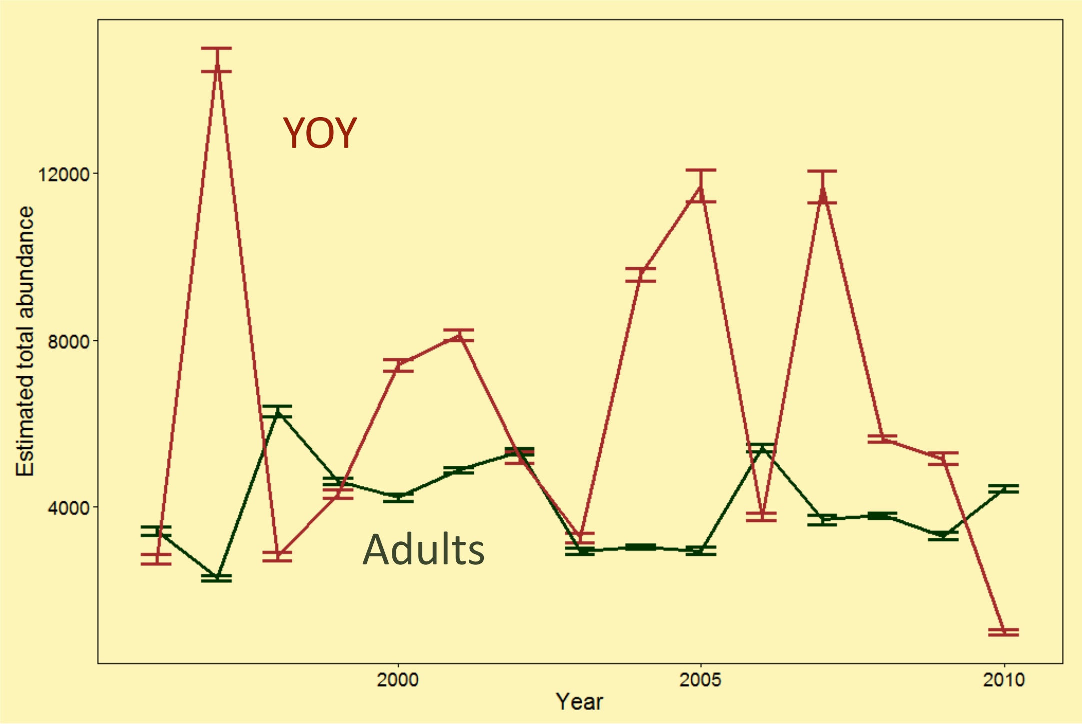
- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
    - Autumn, Winter, Spring Flow
    - Spring Temperature
    - Elevation
  - State space
  - Population projection
  - Still working on NALCC region data
- Presence/absence
  - Occupancy models



Yearly data, many sites

Estimated abundances

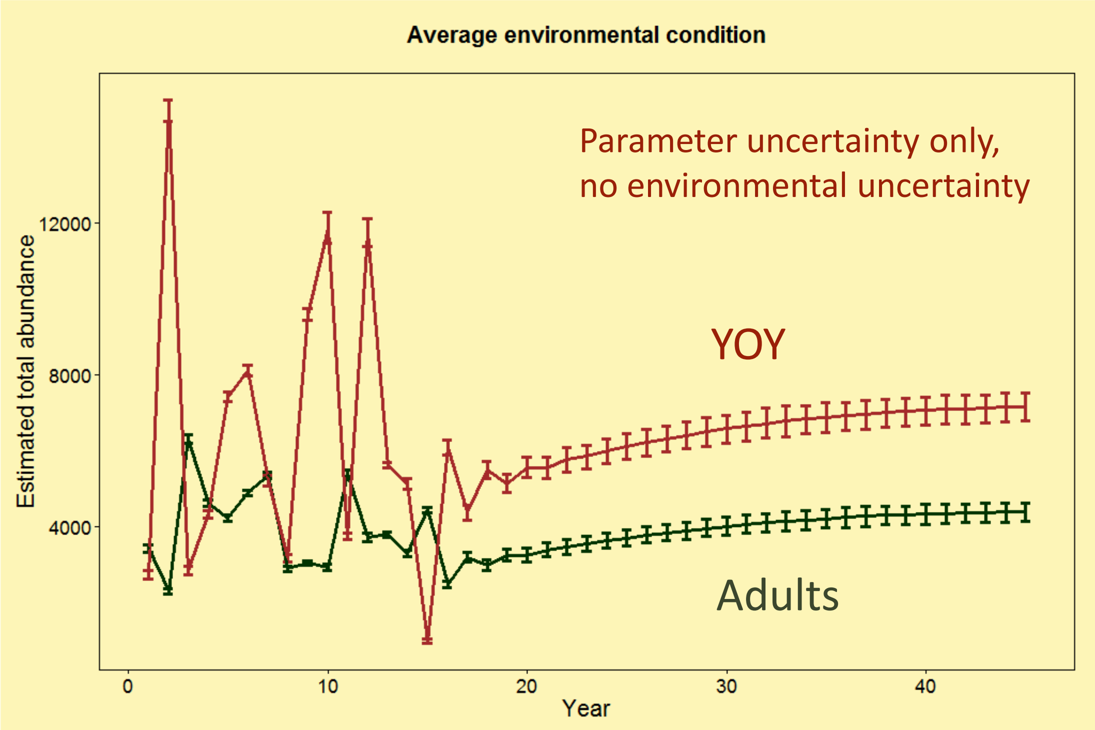
- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
    - Autumn, Winter, Spring Flow
    - Spring Temperature
    - Elevation
  - State space
  - Population projection
  - Still working on NALCC region data
- Presence/absence
  - Occupancy models



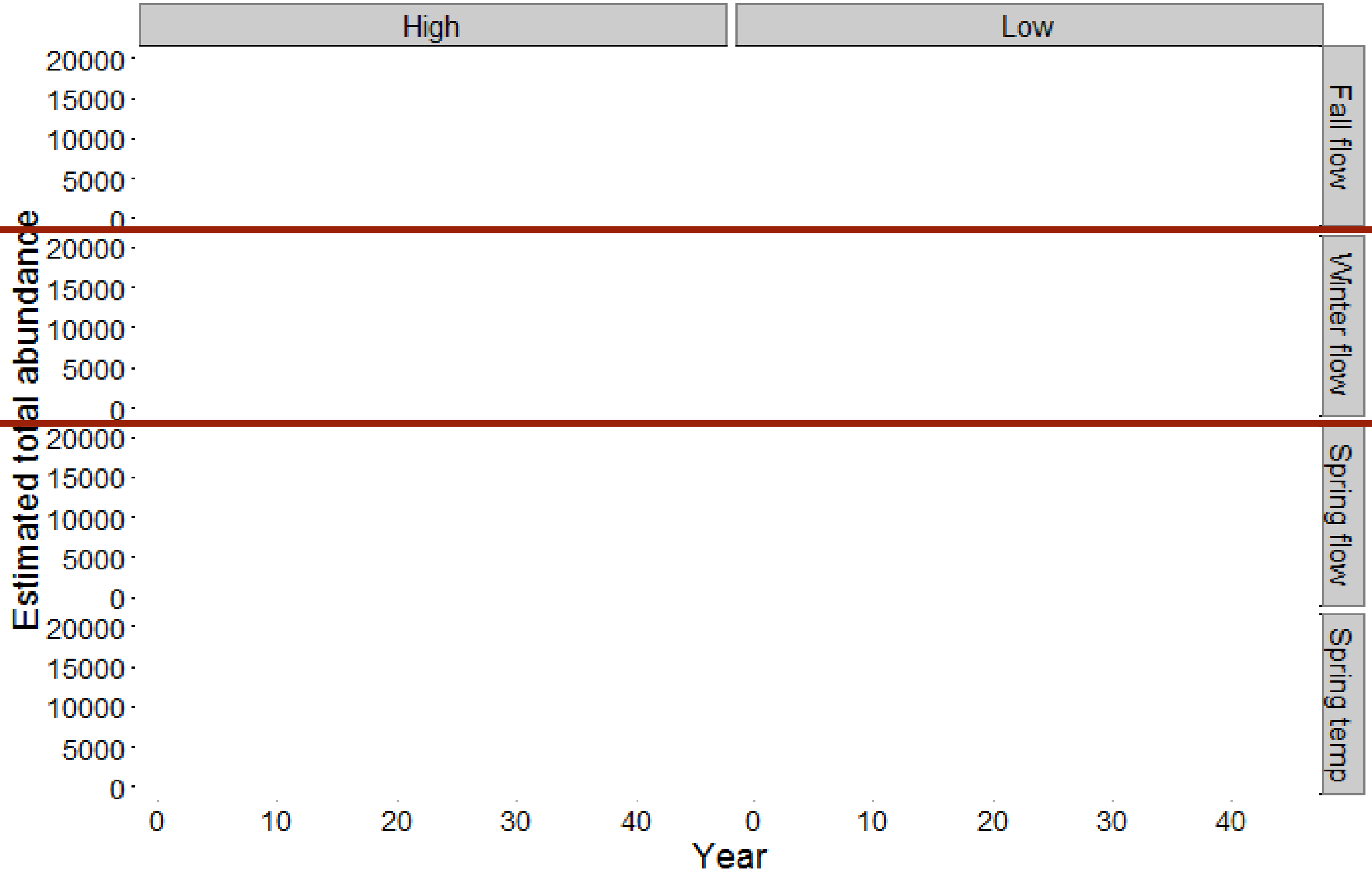
Forecast

- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
    - Autumn, Winter, Spring Flow
    - Spring Temperature
    - Elevation
  - State space
  - Population projection

  - Still working on NALCC region data
- Presence/absence
  - Occupancy models

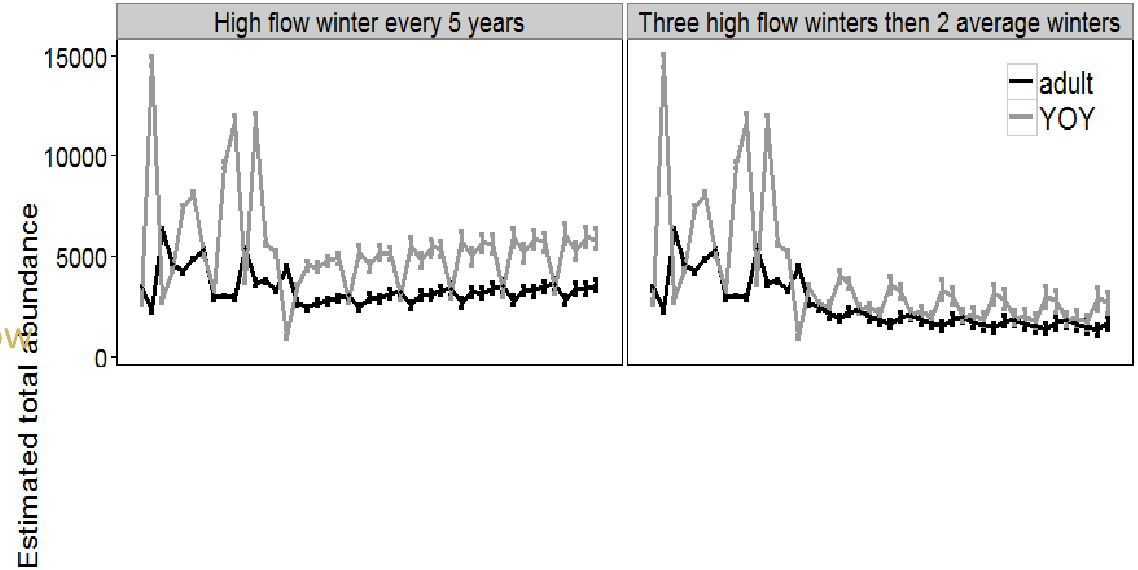


Forecasts


High
Low
Fall flow
Winter flow
Spring flow
Spring temp
Estimated total abundance
20000
15000
10000
5000
0
0
10
20
30
40
Year

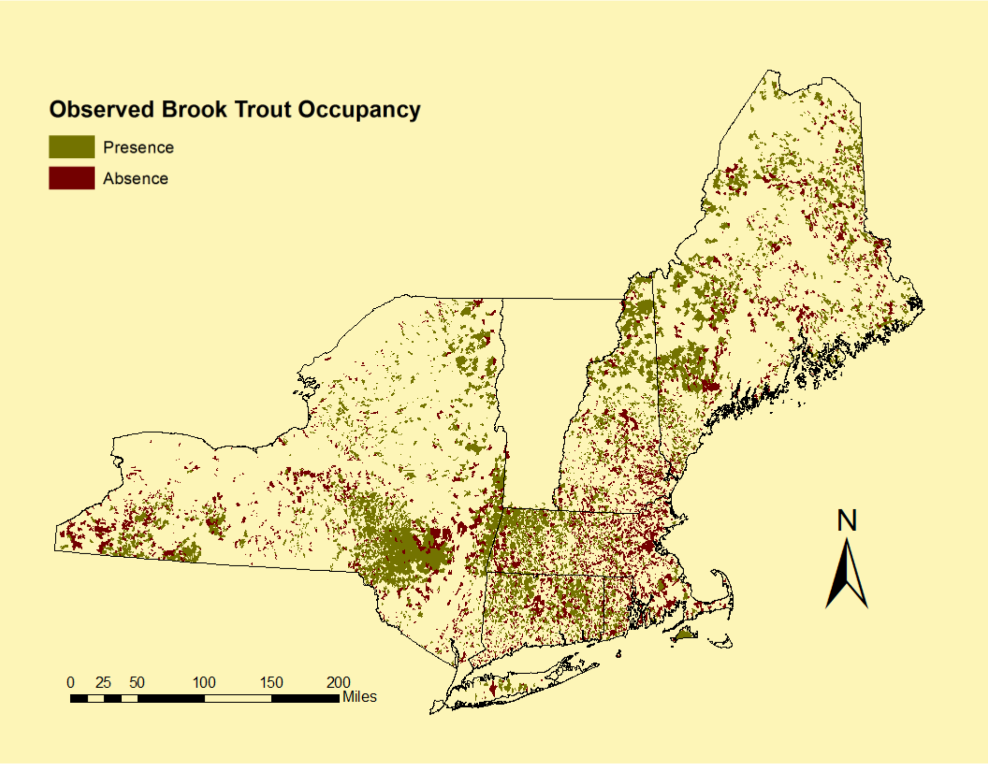
Extreme events forecast

- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
    - Autumn, Winter, Spring Flow
    - Spring Temperature
    - Elevation
  - State space
  - Population projection
- Presence/absence
  - Occupancy models



Data types

- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
- Presence/absence
  - Occupancy models



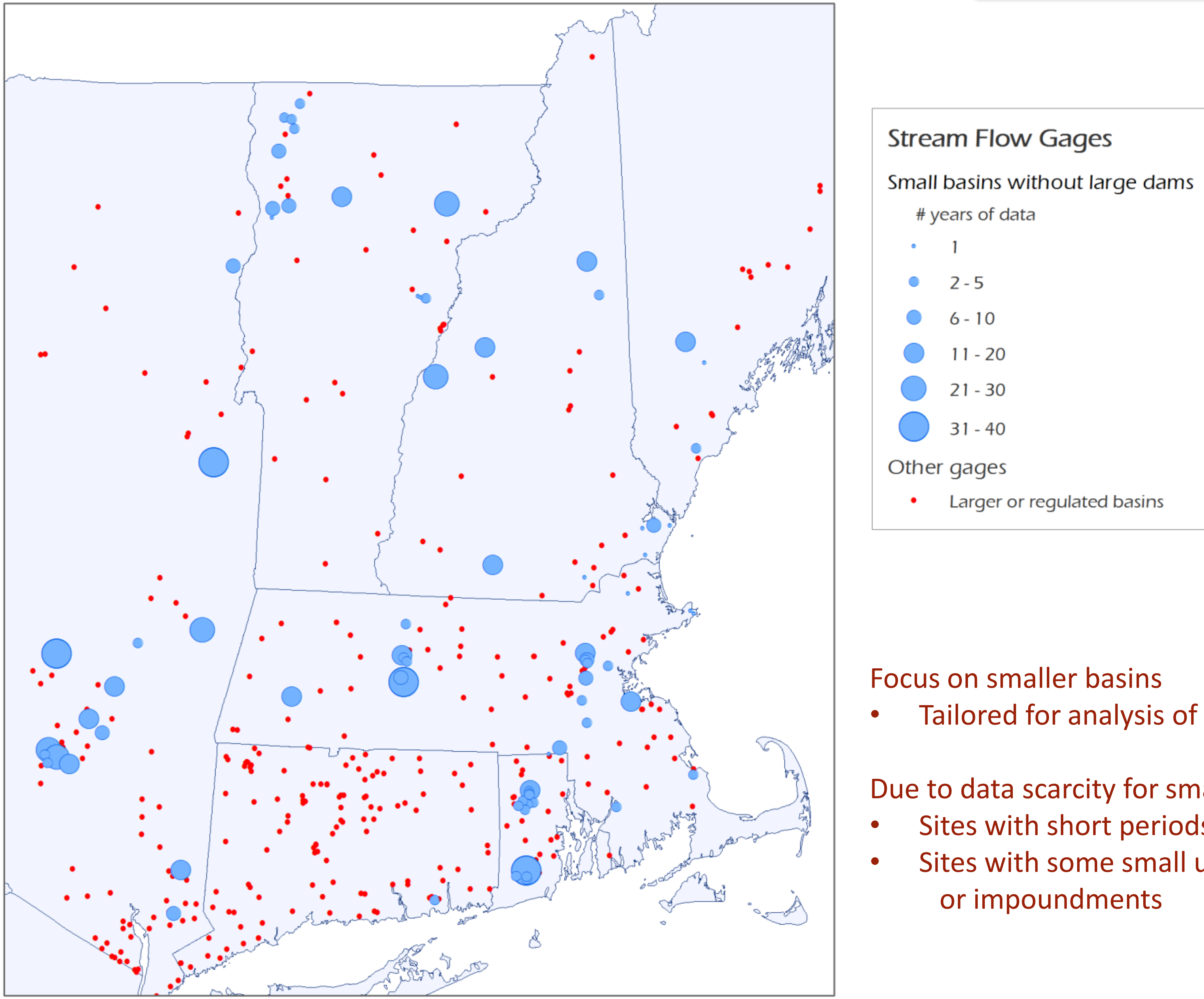
Single or multiple year data, many sites

Model estimates

- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
- Presence/absence
  - Occupancy models
    - Annual stream flow
    - Stream temperature resilience
    - Summer stream temperature max
    - Soil drainage class
    - Drainage area
    - Forest cover
    - Stream slope

Modeled

Stream Flow



Focus on smaller basins

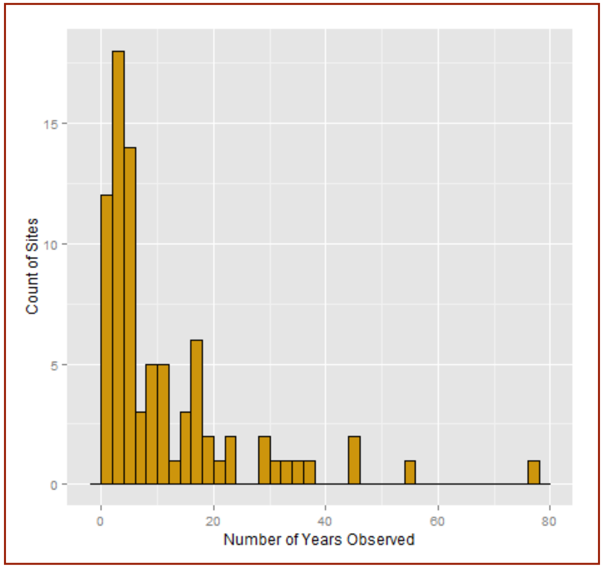
- Tailored for analysis of headwater ecosystems

Due to data scarcity for small basins, include

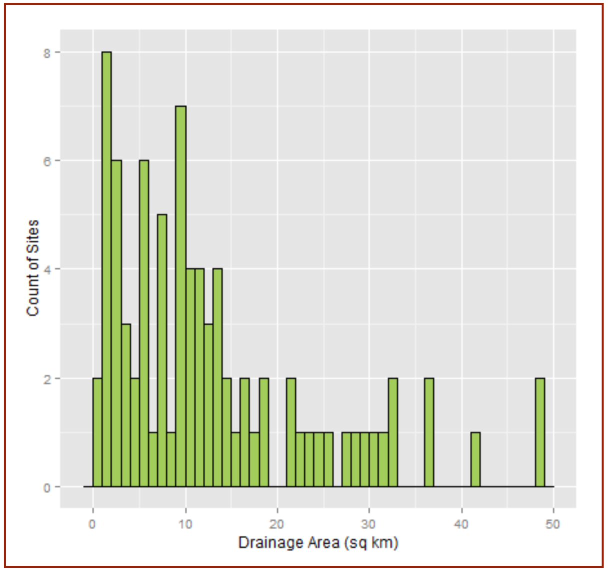
- Sites with short periods of record
- Sites with some small upstream dams or impoundments

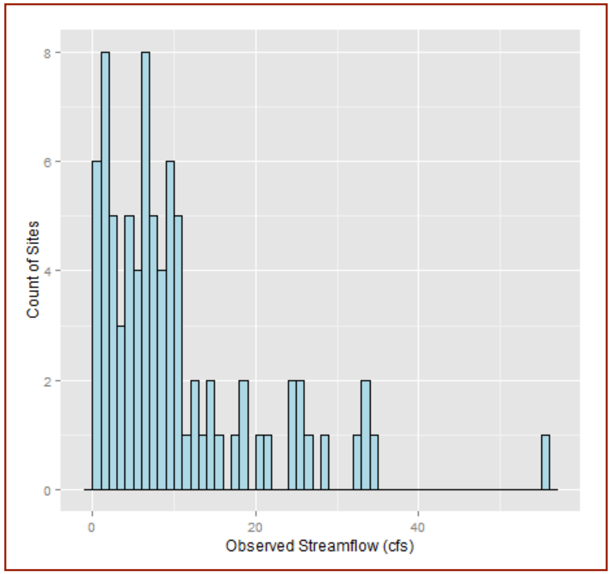
Streamflow gaged data used for statistical streamflow model

Number of Years Observed

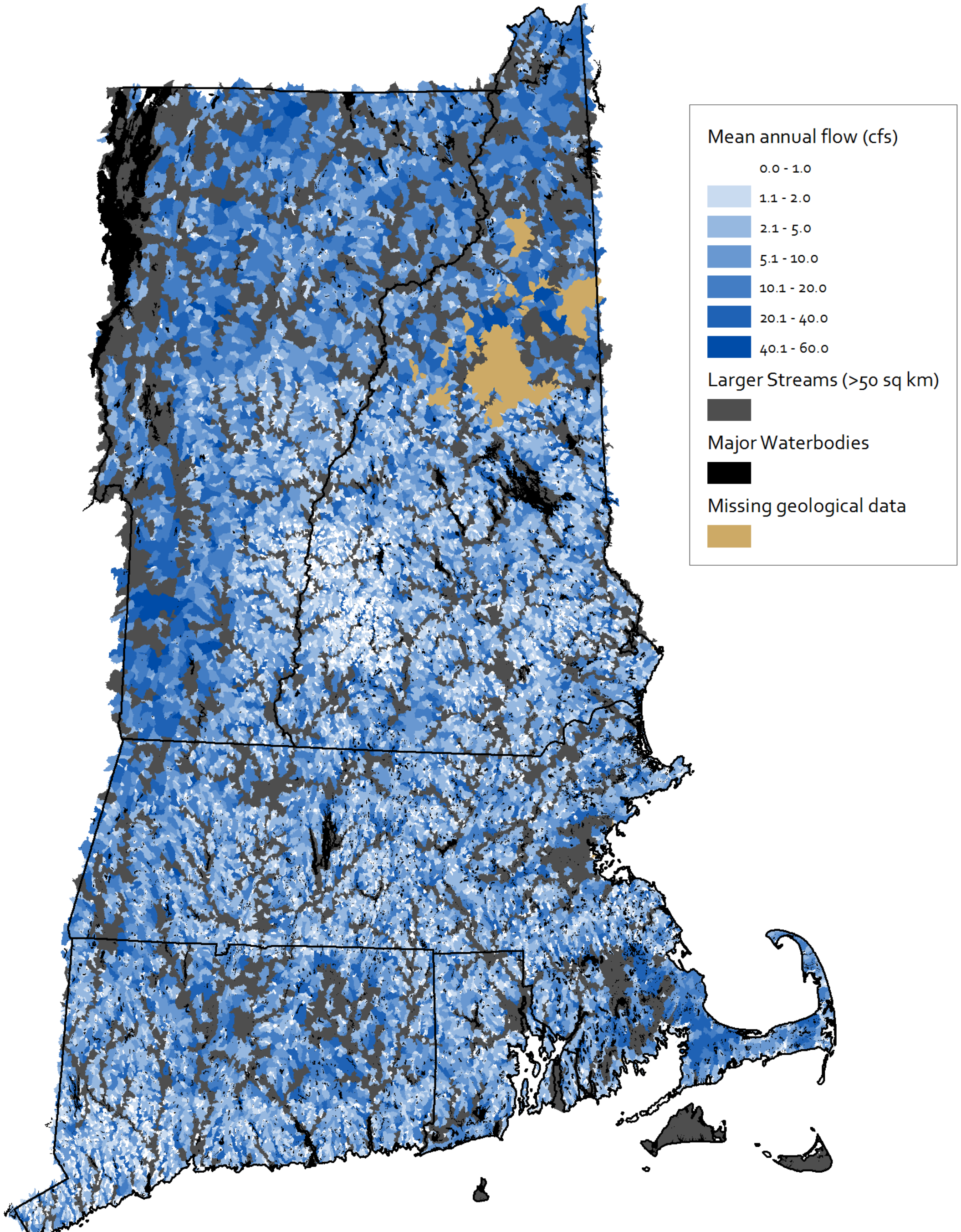


Basin size and mean streamflow





Stream Flow



Weighted Least Squares model of long-term mean annual flow and other inter-annual statistics

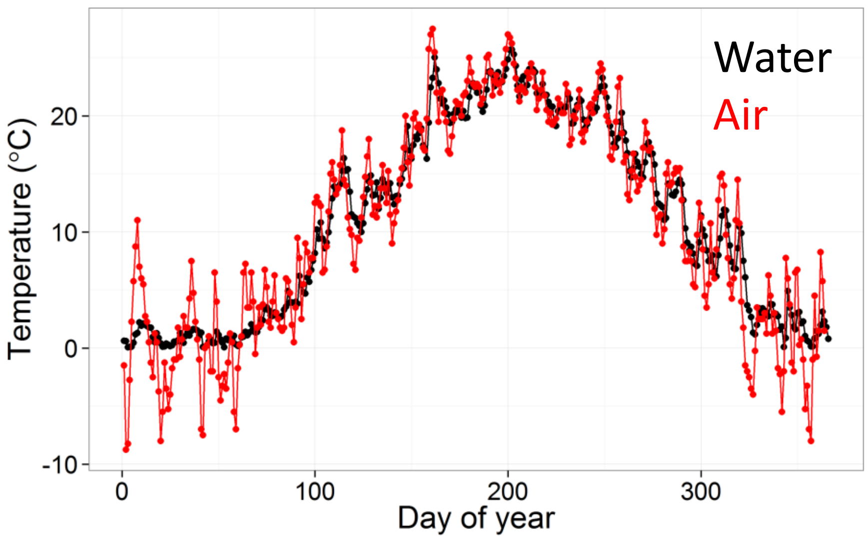
Driven by basin characteristics:

Drainage area	+
Precipitation	+
Developed Area	-
Hydrologic Soils A & B	-

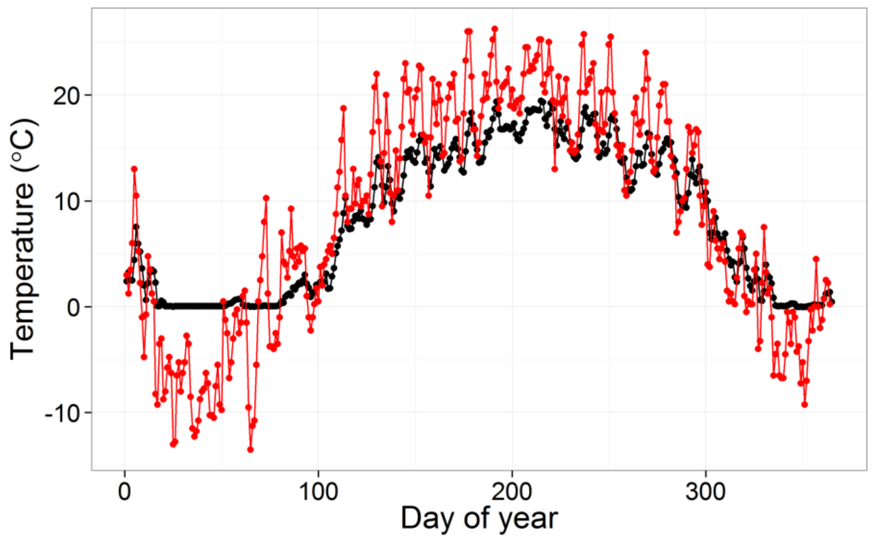
R-squared: ~ 95%
(for mean annual flow)

Additional model under development includes year-specific meteorological data, to better utilize sites with short records

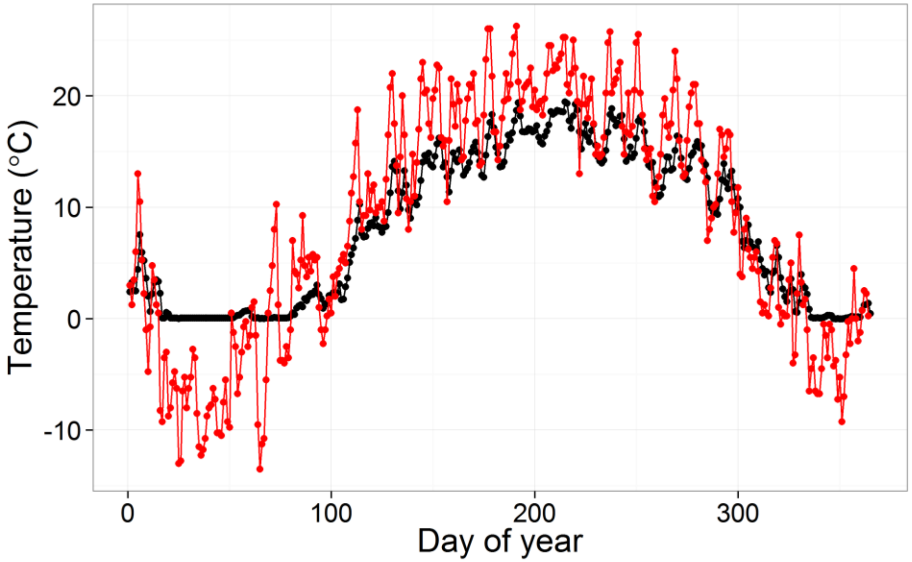
Stream 1

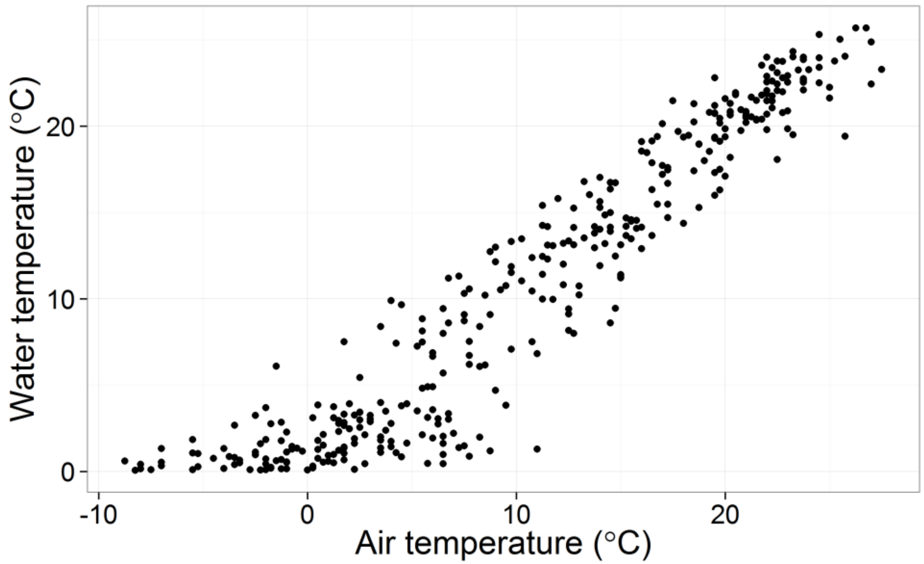


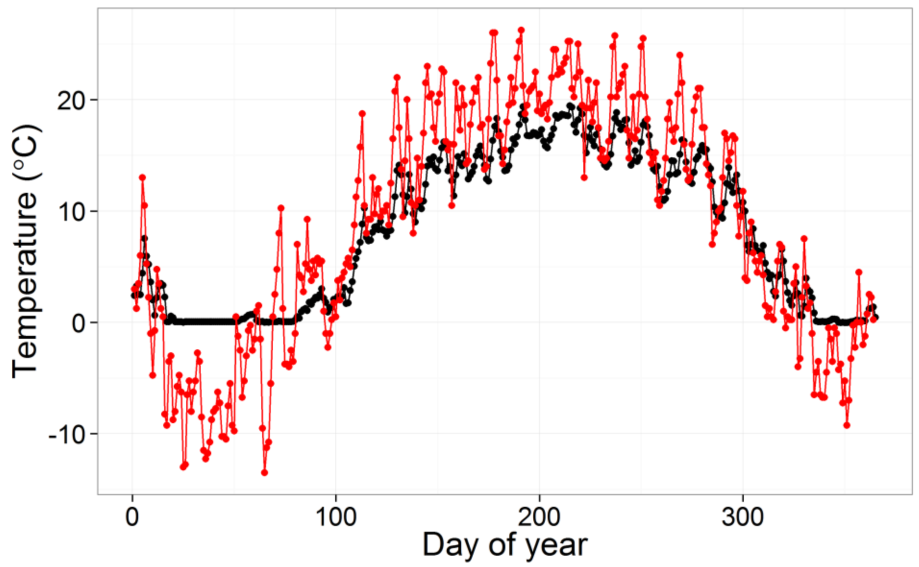
Stream 2

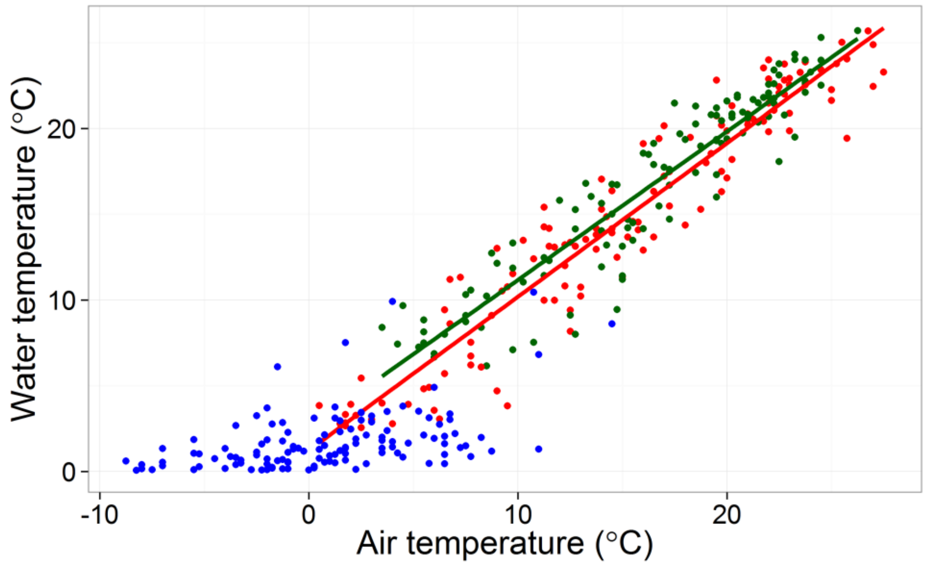


Can we model year-round stream temperature as a function of air temperature and catchment characteristics?


Temperature (°C)
20
10
0
-10
0
100
200
300
Day of year

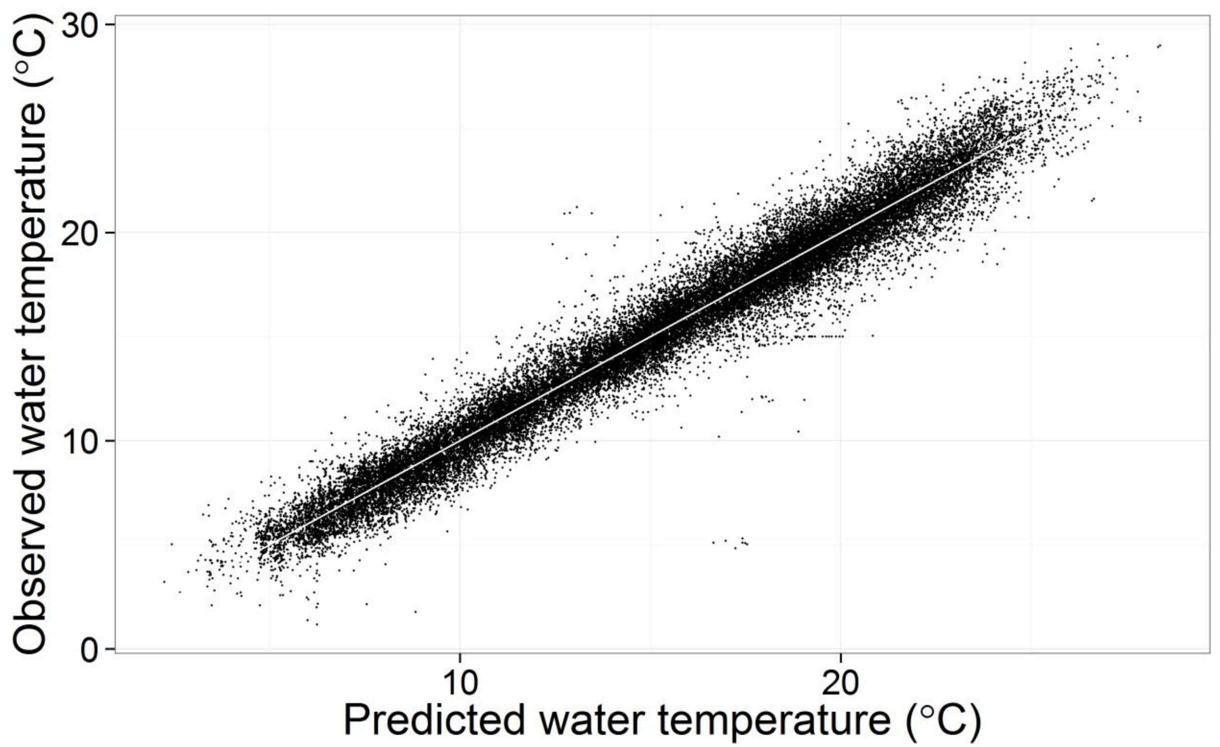

Water temperature (°C)
20
10
0
-10
0
10
20
Air temperature (°C)


Temperature (°C)
20
10
0
-10
0
100
200
300
Day of year


Water temperature (°C)
20
10
0
-10
0
10
20
Air temperature (°C)

Synchronization approach

- Advantages
  - Good daily estimates for spring-fall (primary ecological concern)
  - Can use partial-year data
  - Useful metrics



R^2 = 0.96, RMSE =1.0 ºC

Synchronization approach

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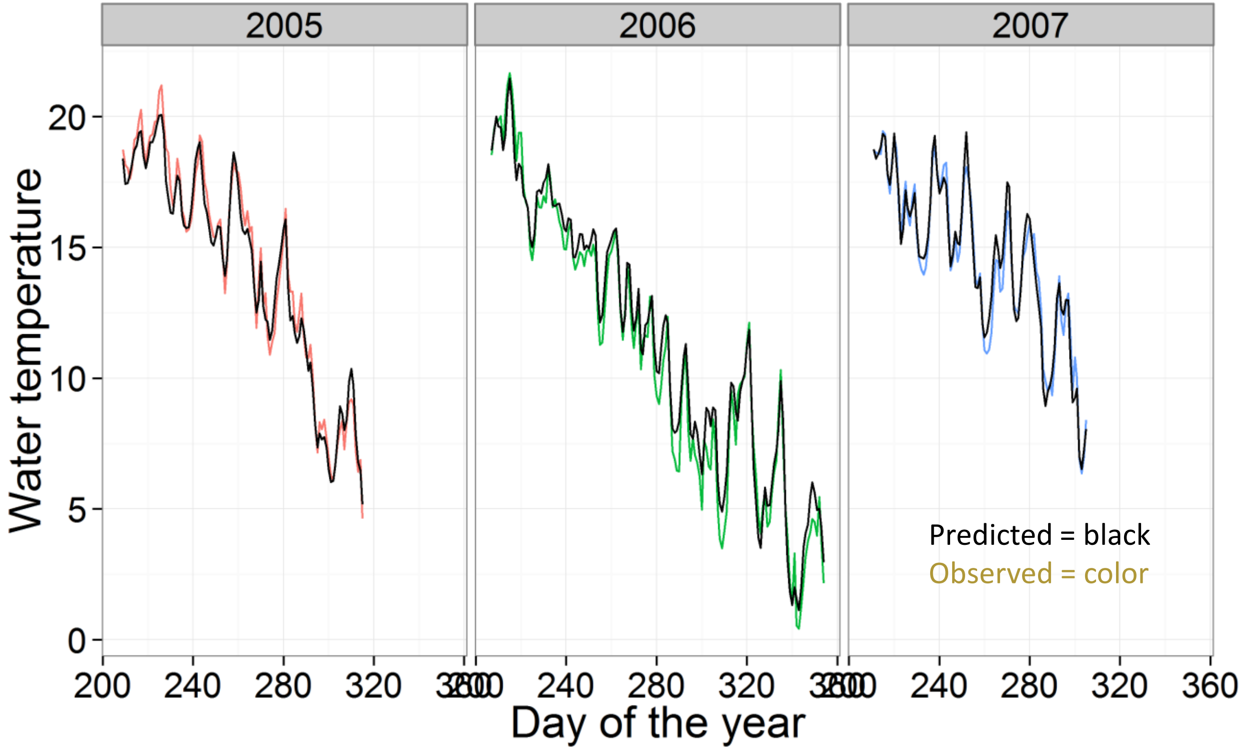
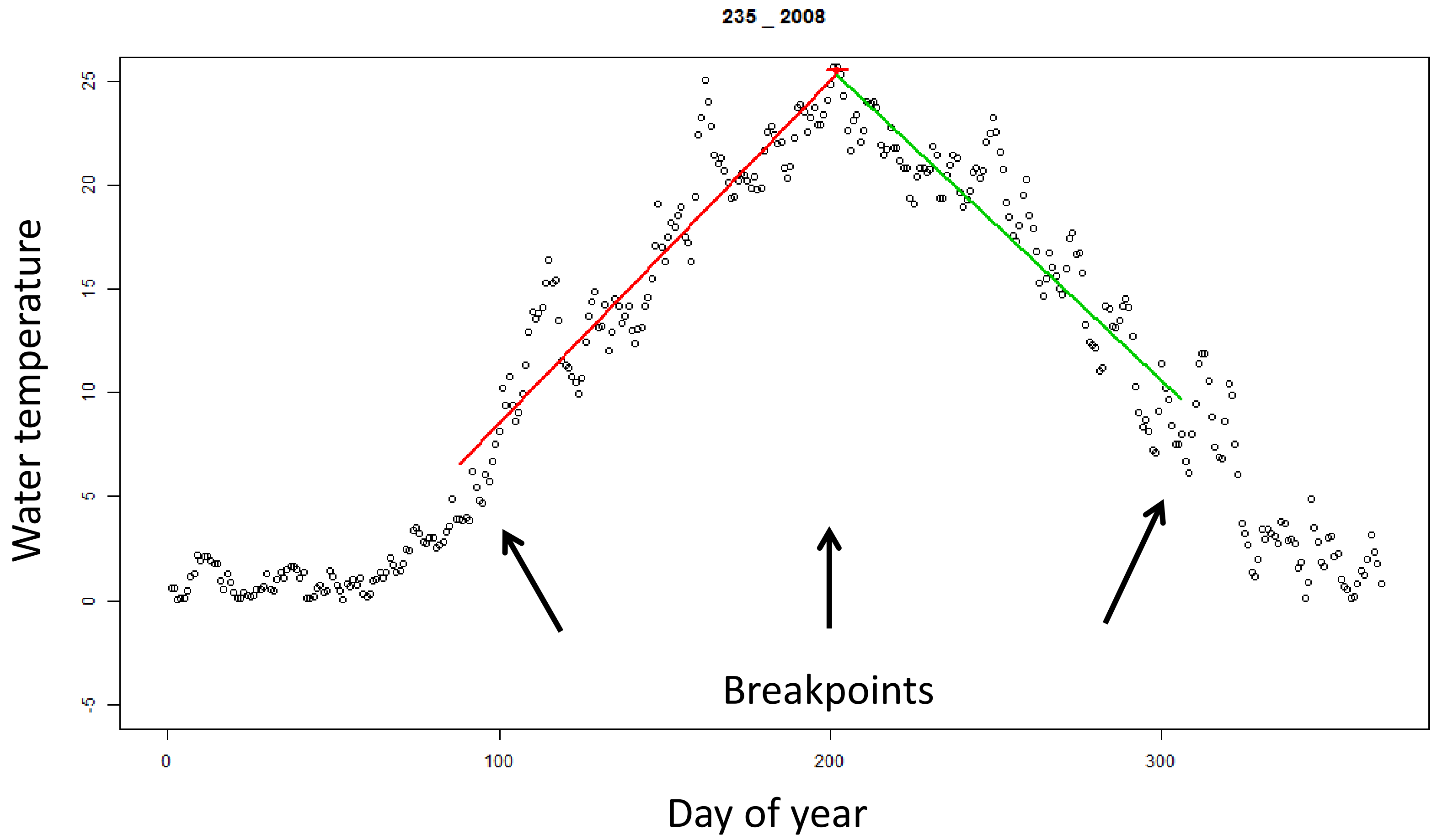
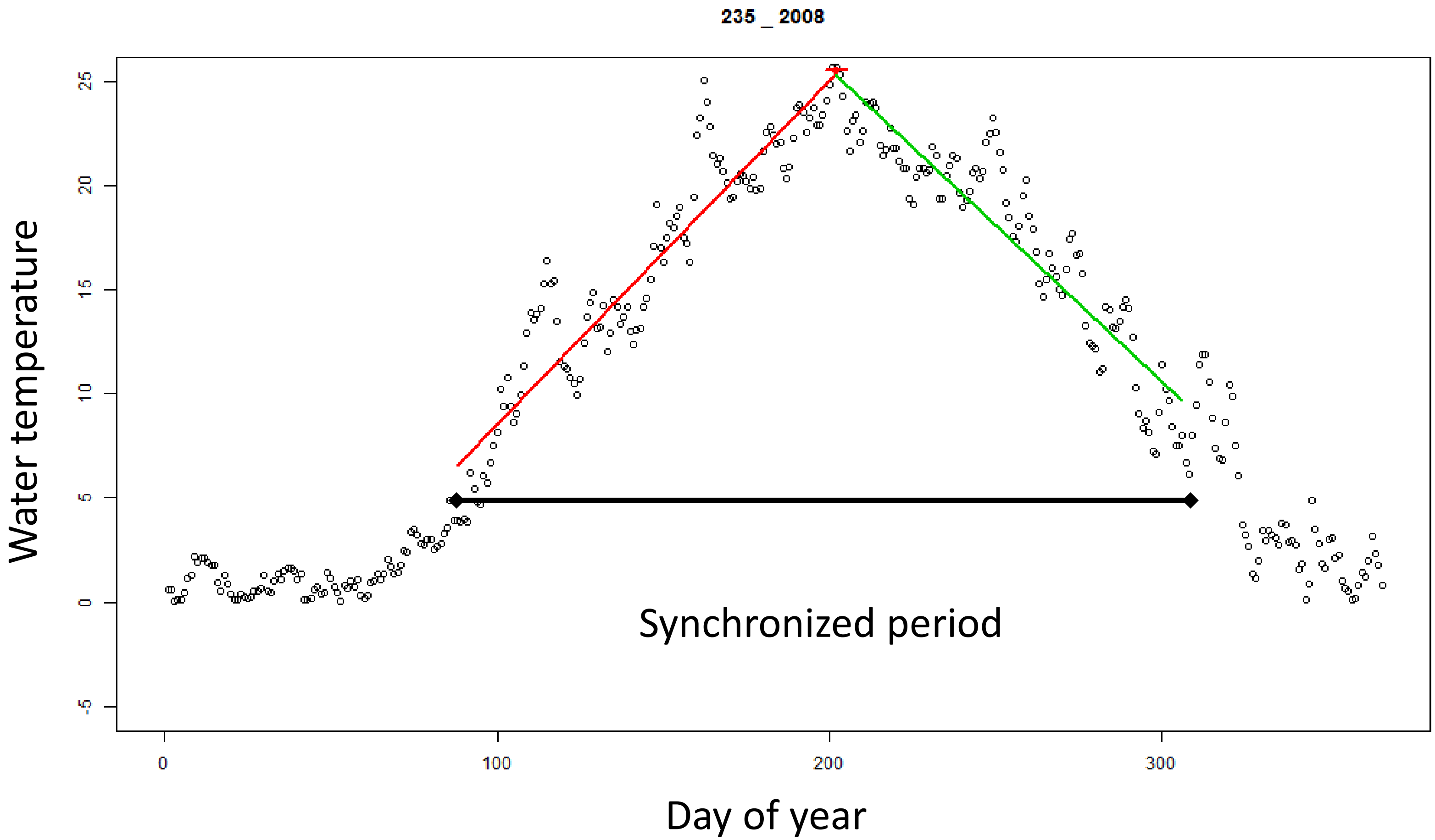


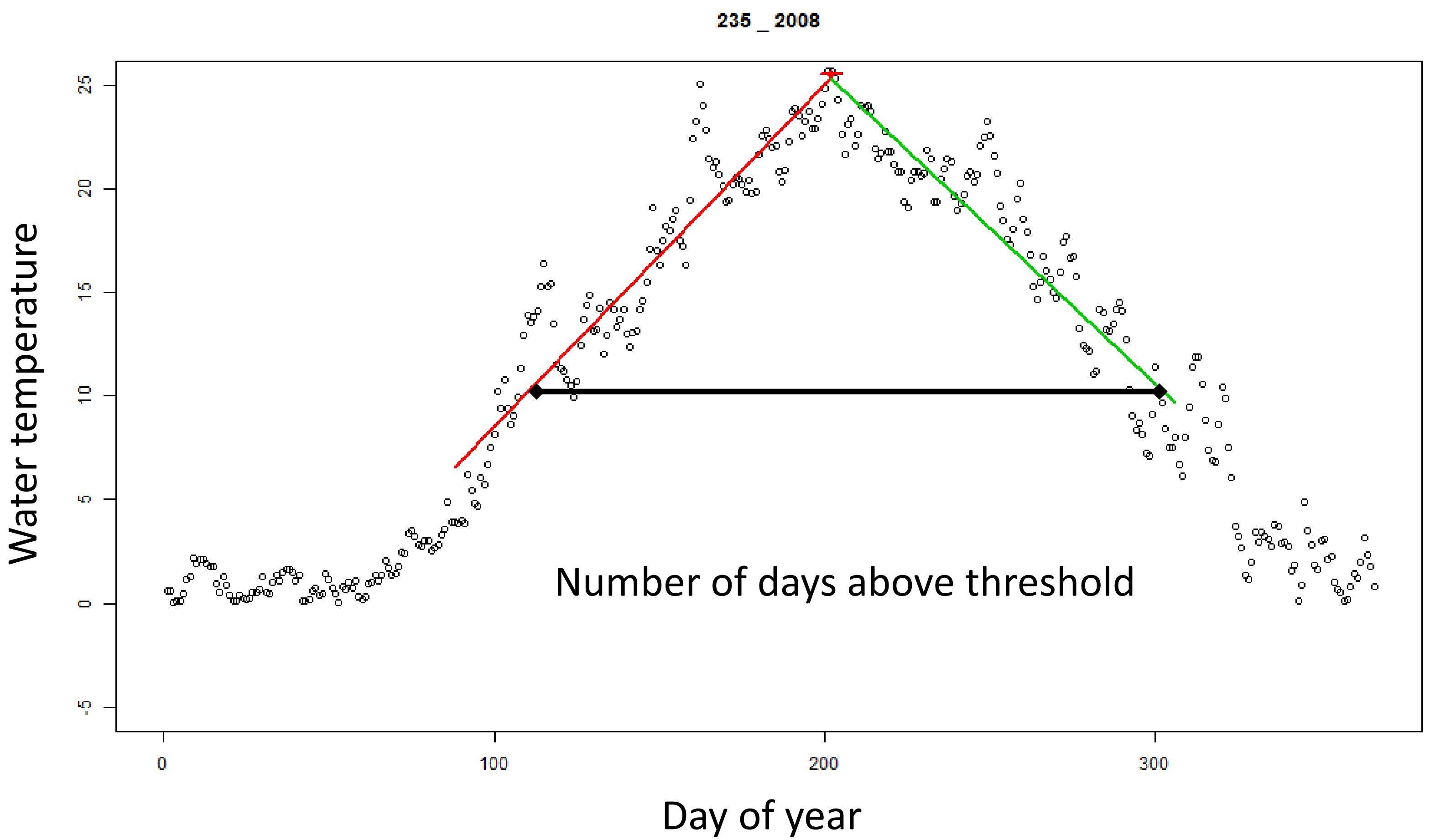
Metrics


235 _ 2008
Water temperature
25
20
15
10
5
0
-5
0
100
200
300
Breakpoints
Day of year

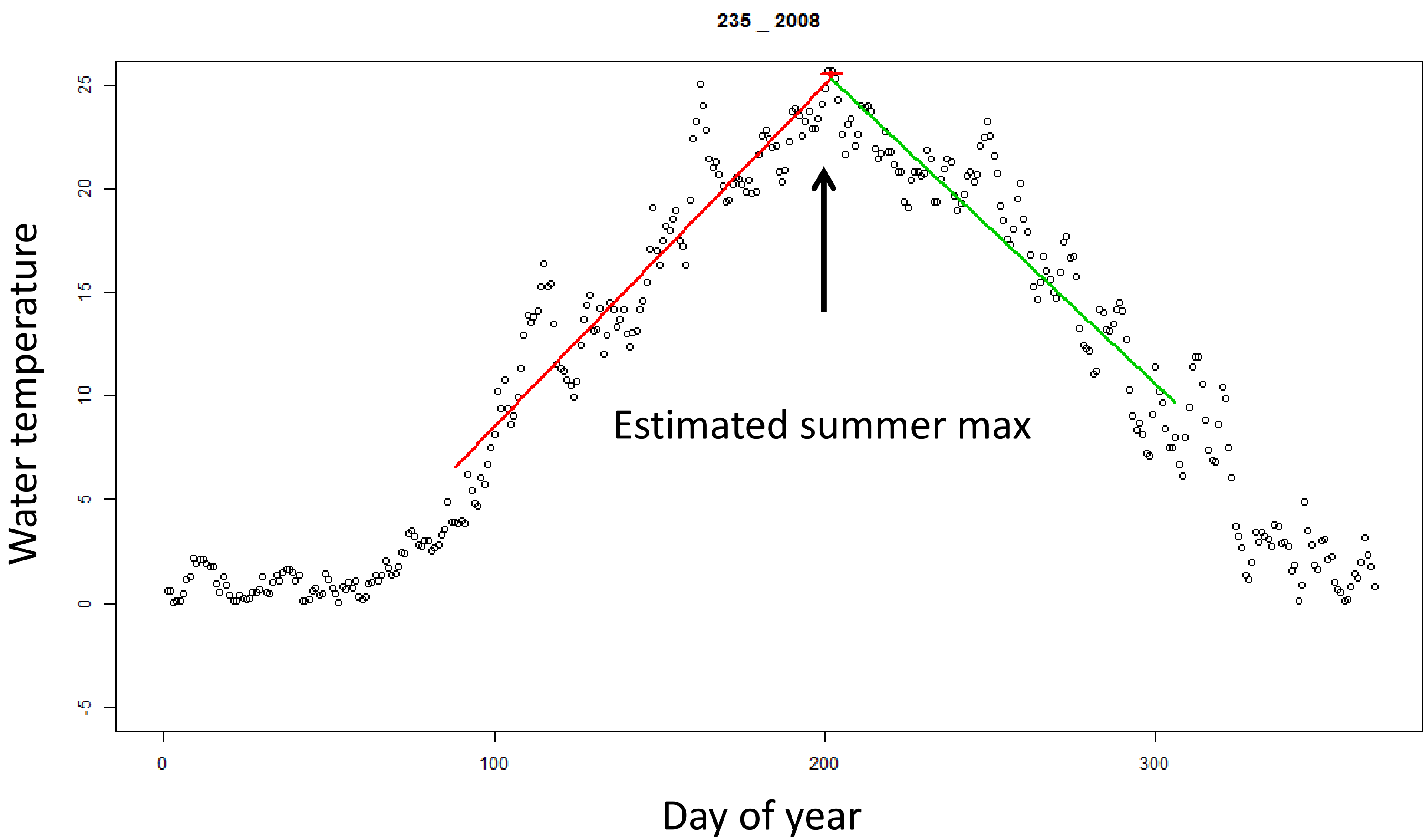
Metrics


235 _ 2008
Water temperature
Day of year
Synchronized period
25
20
15
10
5
0
-5
0
100
200
300

Metrics


235 _ 2008
Water temperature
25
20
15
10
5
0
-5
0
100
200
300
Day of year
Number of days above threshold

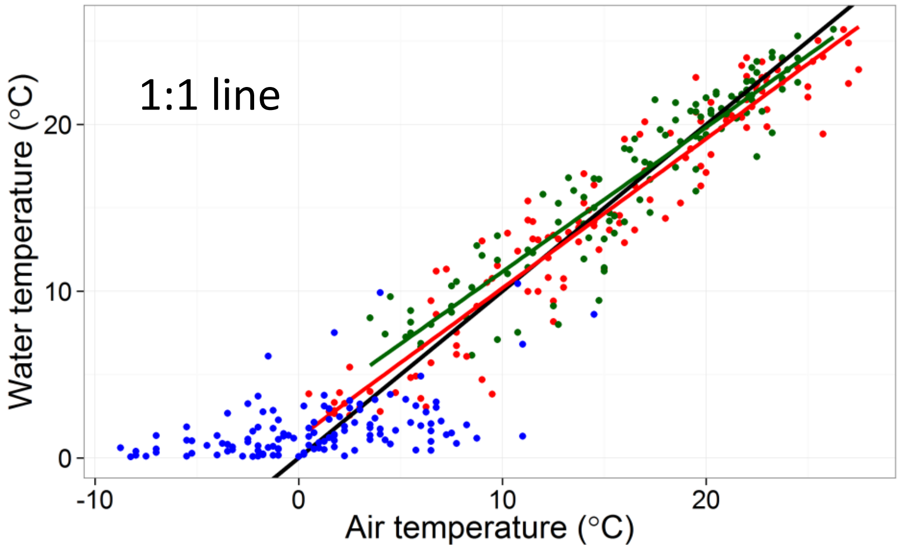
Metrics



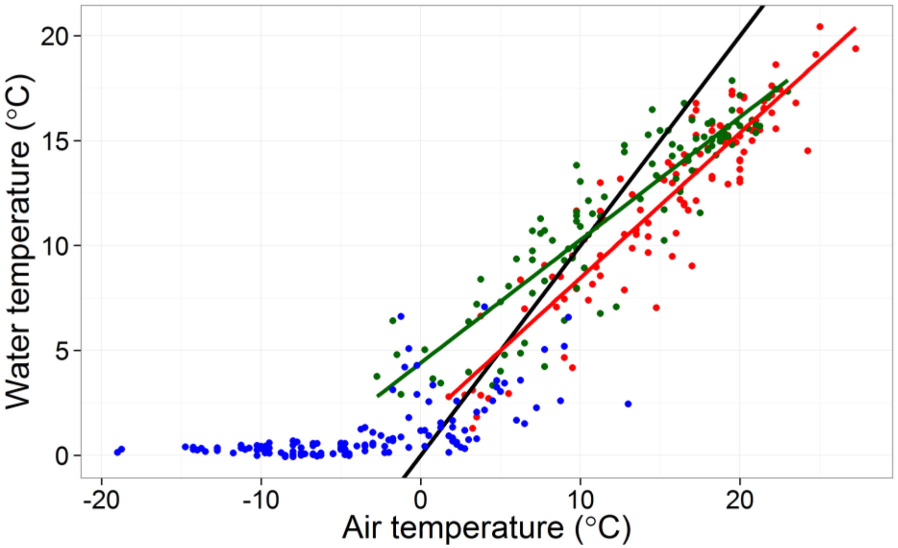
235 _ 2008
Estimated summer max
Water temperature
Day of year
-5
0
5
10
15
20
25
0
100
200
300

Metrics

Less resilient



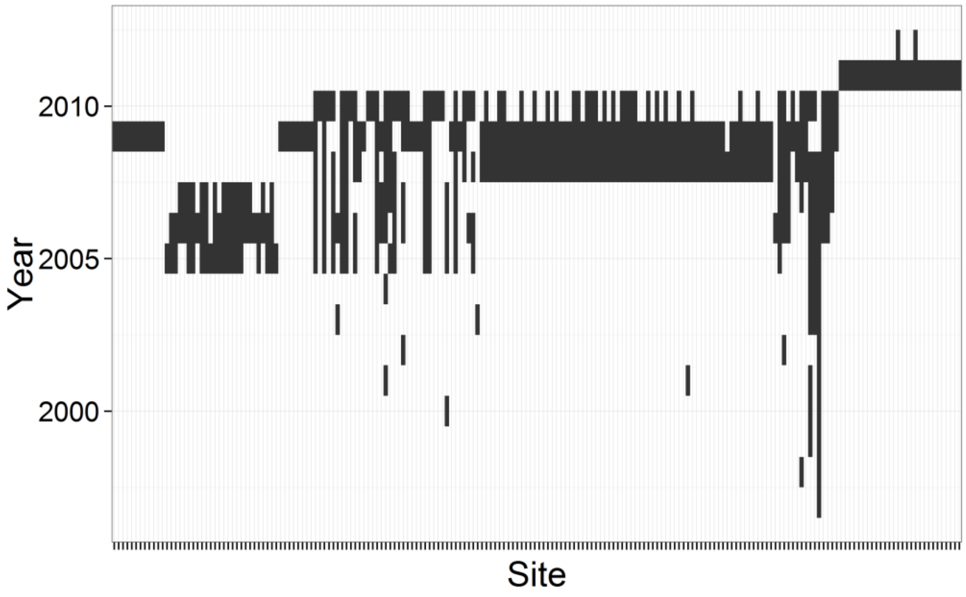
More resilient

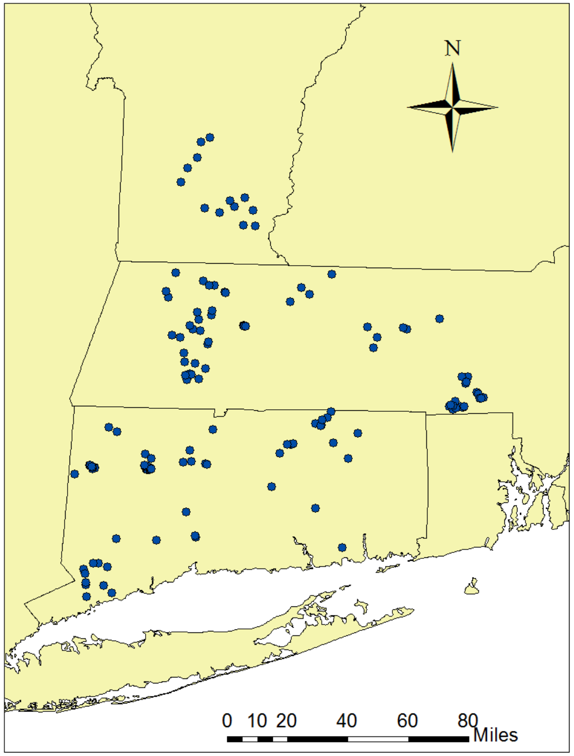


Slopes ~ resilience to air temperature change

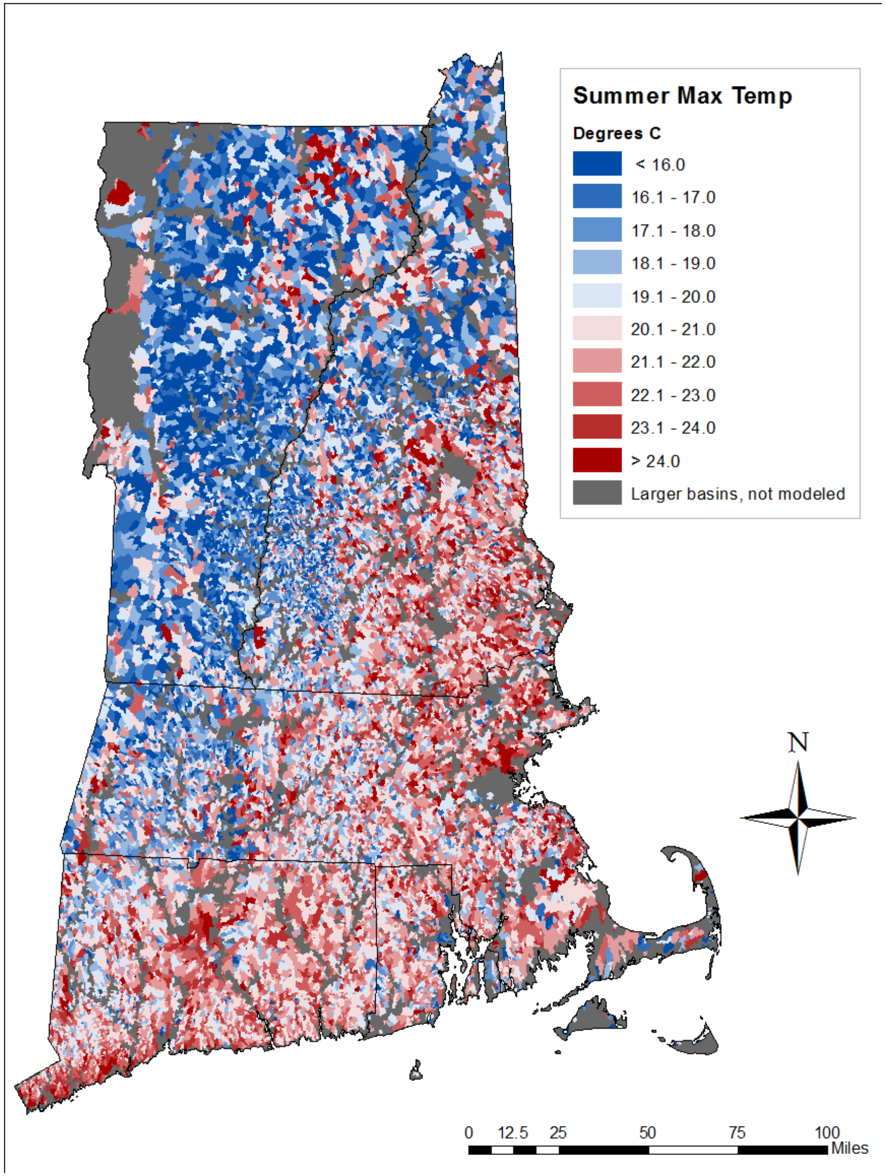
Existing water temperature data

- 195 sites, scattered over 1997-2012
- > 41,000 observations

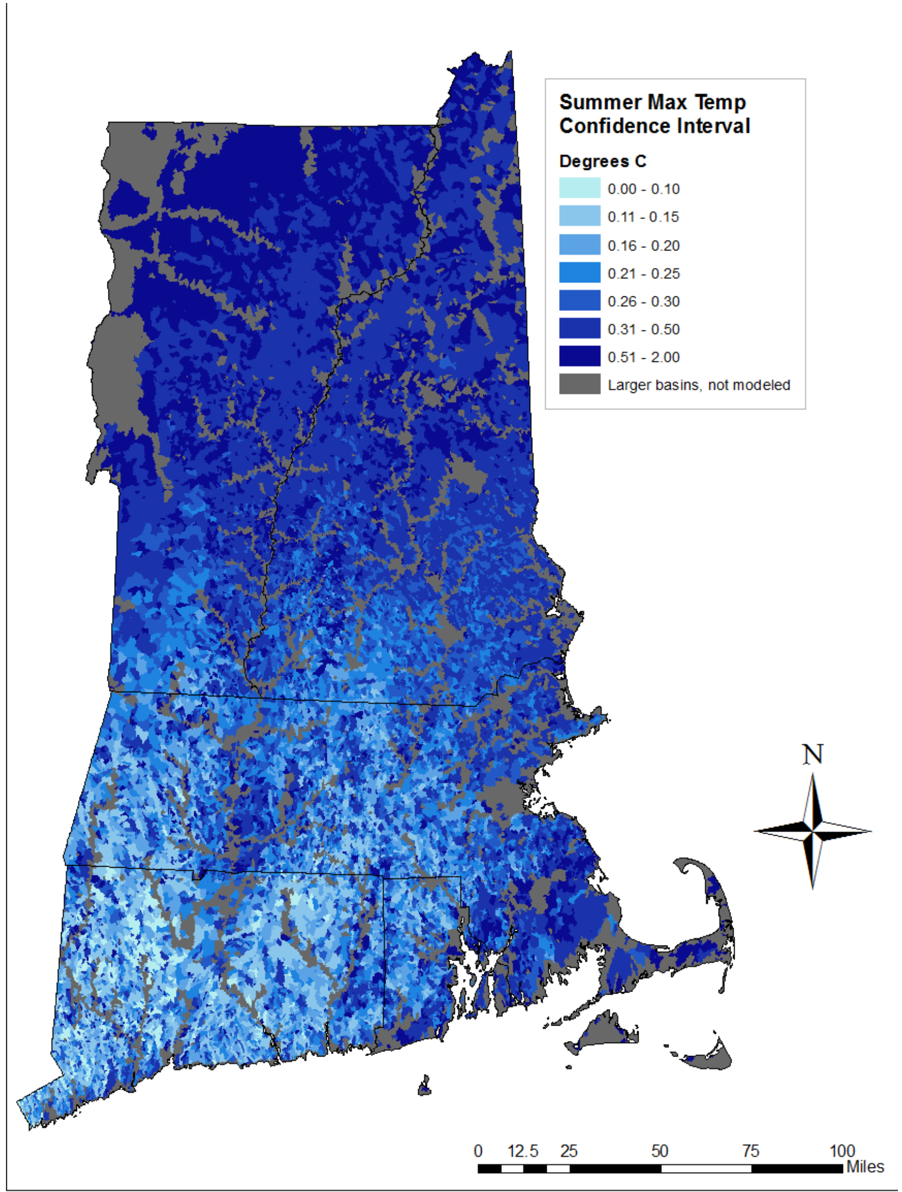




Summer Maximum Stream Temperature

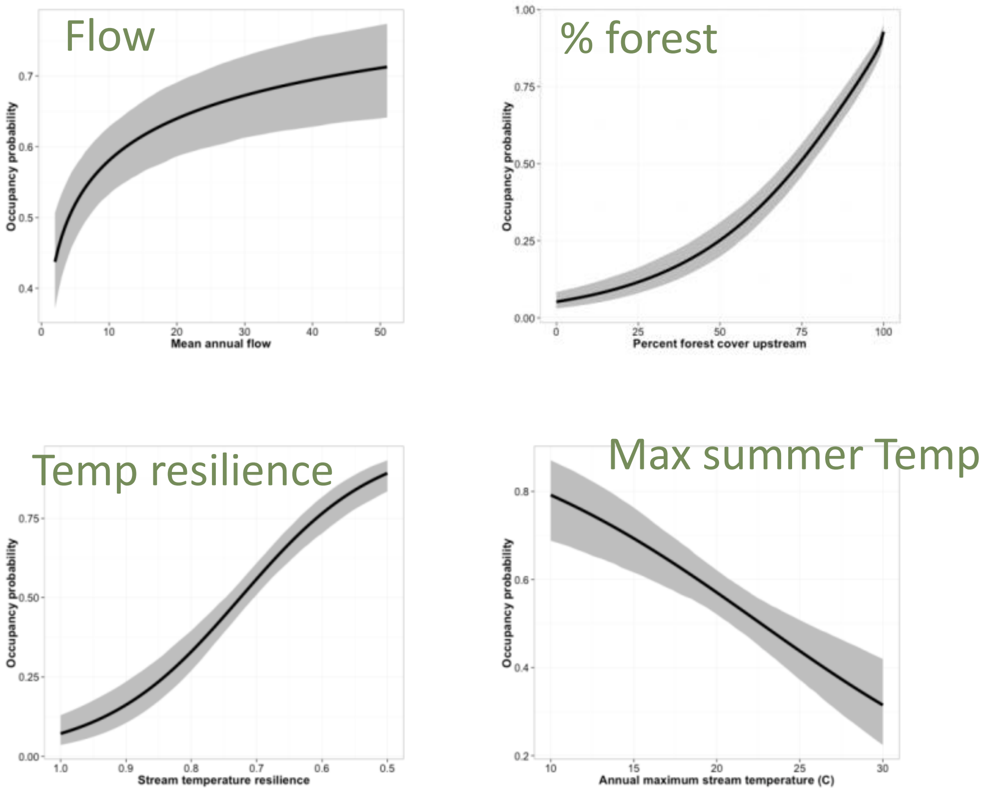


Summer Maximum Temperature Confidence Intervals

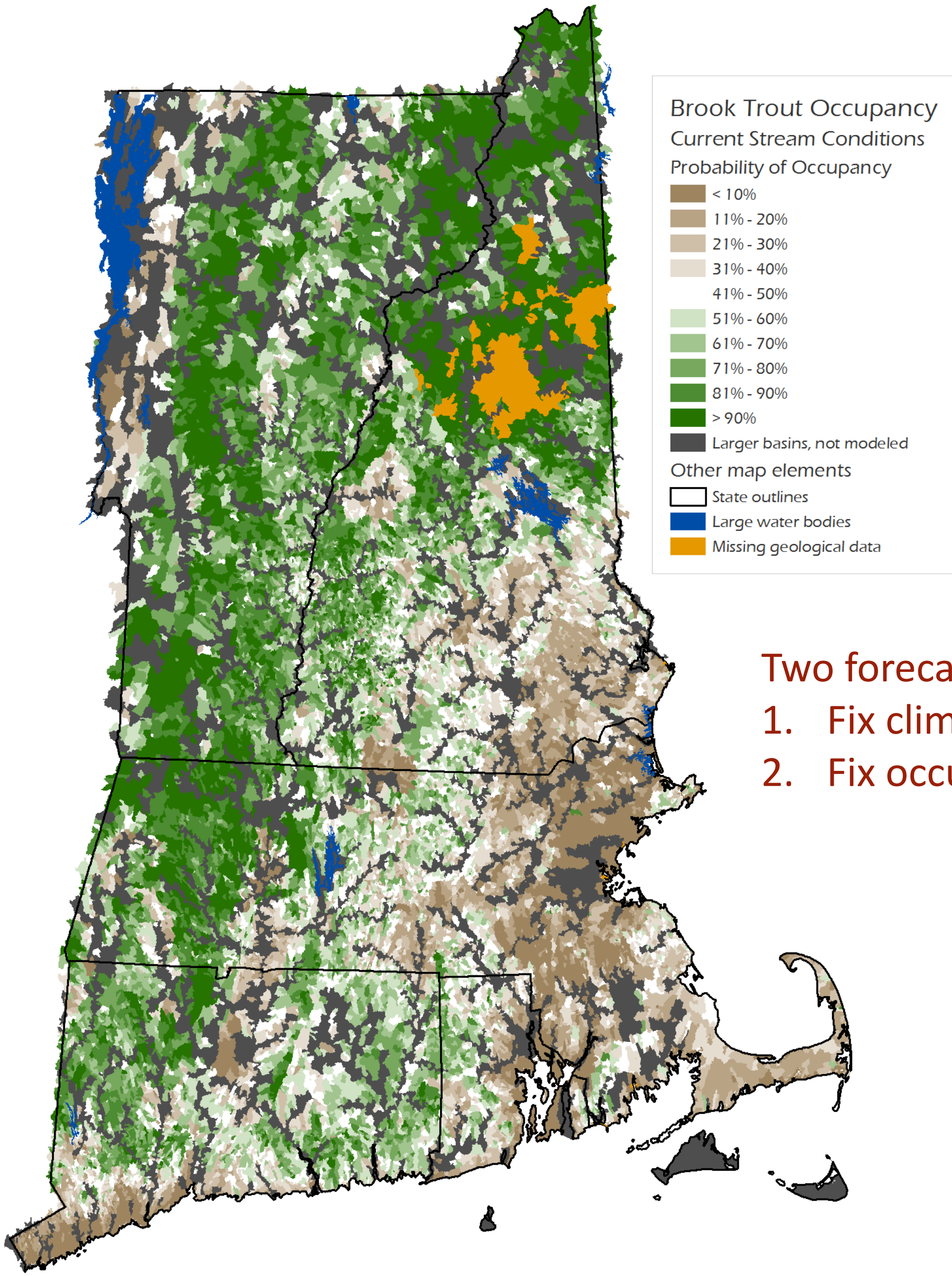


Model estimates

- PIT tag
  - Single-site demographic model
- Abundance
  - Abundance models
- Presence/absence
  - Occupancy models
    - Annual stream flow
    - Stream temperature resilience
    - Summer stream temperature max
    - Soil drainage class
    - Drainage area
    - Forest cover
    - Stream slope



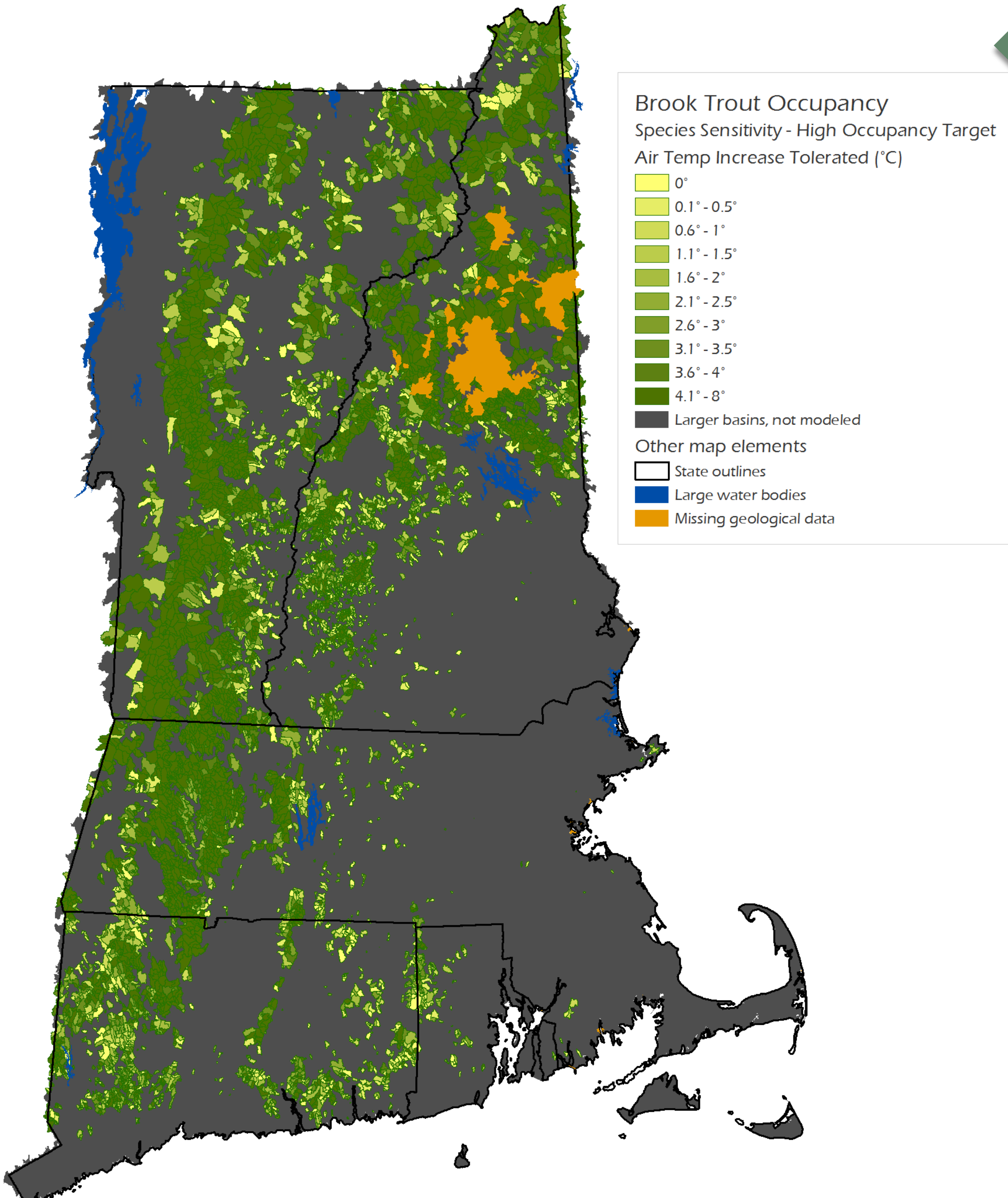
Brook Trout Occupancy Model



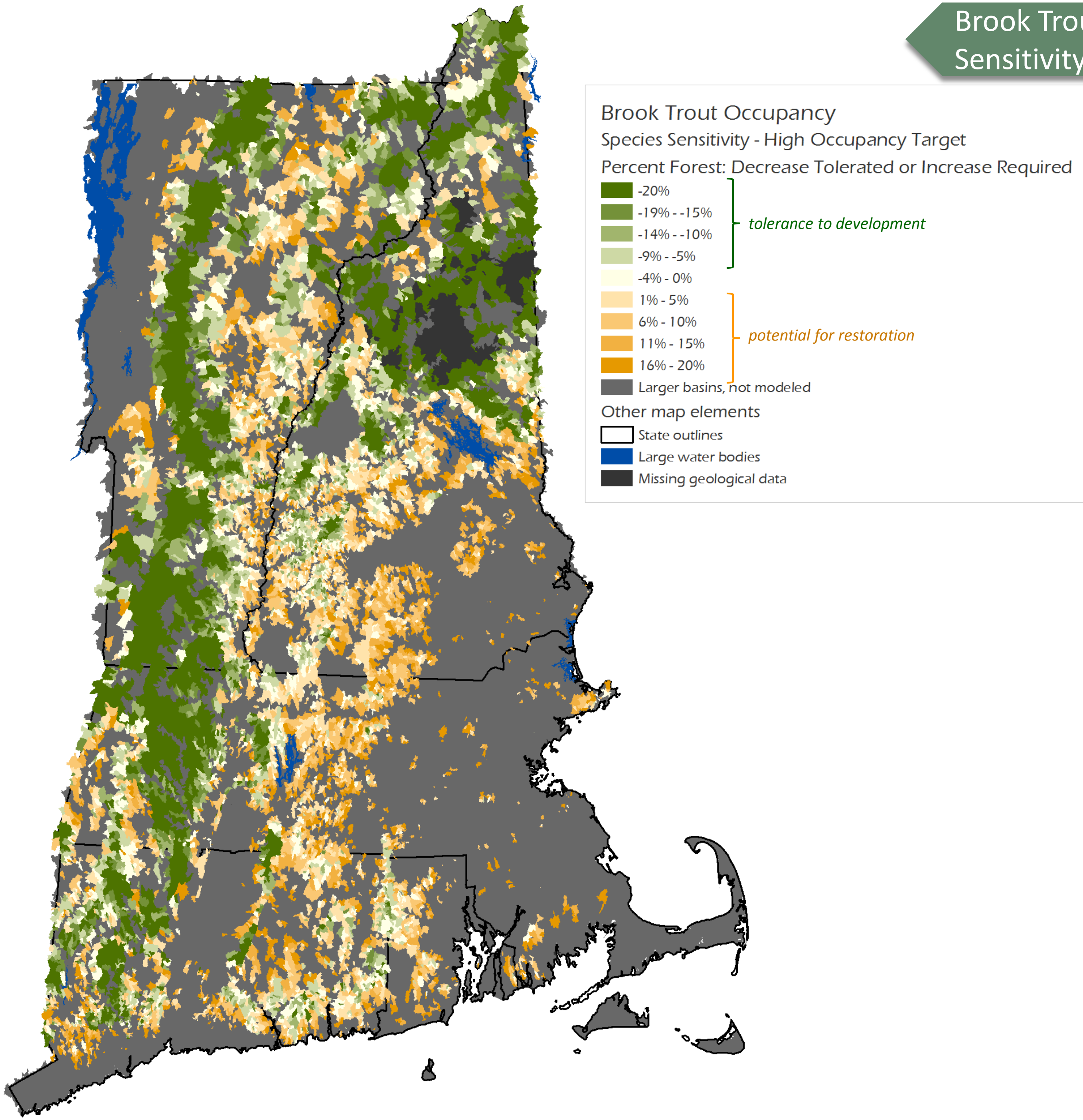
Two forecasting options:

1. Fix climate, look at how occupancy varies
2. Fix occupancy, look at sensitivity to climate

Brook Trout Occupancy Sensitivity to Climate Change



Brook Trout Occupancy Sensitivity to Forest Change



Bringing it together

Variable	Season	Model		
		Single-site demographic	Multiple-site demographic	Occupancy
Stream flow	Fall	↑ **	↑ ***	Flow ↑
	Winter	↓ **	↓ **	
	Spring	↔	↔	
	Summer	↑ ***	NA	
St. temperature	Fall	↓ **	NA	Temperature ↓
	Winter	↔	NA	
	Spring	↔	↔	
	Summer	↓ ***	NA	

Summary

- Congruent environmental effects on population growth across scales
  - Increases confidence in generality of results
  - Negative effects of temperature
  - Positive effects of flow in fall and summer, negative effects in winter

- Many brook trout populations at risk in future
  - Flow and temperature
  - Extreme events

- Can identify resilient populations and potentially mitigating factors

Maps available at:
http://felek.cns.umass.edu:8080/geoserver/www/gismapper/index.html?app=nalcc#

Papers

Kanno, Y, B. H. Letcher, J.C. Vokoun and E.F. Zipkin, **in Press**, Spatial variability in survival of adult brook trout within two intensively surveyed headwater stream networks, CJFAS

Zipkin,E., J. Thorson, K. See, H. Lynch, E. Grant, Y. Kanno, R. Chandler, B.H. Letcher, and J. Royle. **in Press** Modeling structured population dynamics using data from unmarked individuals. Ecology doi:10.1890/13-1131.1

Kanno, Y, B. H. Letcher, J Coombs, and K.H. Nislow, 2013. Linking fish movement and reproductive history to assess habitat connectivity in a heterogeneous stream network, Freshw. Biol. 59(1): 142-154 doi:10.1111/fwb.12254

Kazyak, D., O'Donnell, M.O., Zydlewski, J. and B. H. Letcher, 2013. Growth variability of Brook Charr (*Salvelinus fontinalis*) in coastal Maine, Ecol Freshw Fish. doi: 10.1111/eff.12105

Kanno, Y, J.C. Vokoun, and B. H. Letcher, 2013. Paired stream-air temperature measurements reveal fine-scale thermal heterogeneity within headwater brook trout stream networks, River Research and Applications. 10.1002/rra.2677

Whiteley, A; Coombs, J; Hudy, M; Robinson, Z; Colton, A; Nislow, K; Letcher, BH., 2013. Fragmentation and patch size shape genetic structure of brook trout populations. CJFAS. 70(5): 678-688, 10.1139/cjfas-2012-0493.

Steinschneider S., Polebitski A, Brown C, Letcher BH. 2012. Towards a statistical framework to quantify the uncertainties of hydrologic response under climate change, Water Resources Journal, 48, W11525, 10.1029/2011WR011318

Sigourney, D. B., Munch, S. B., & Letcher, B. H., 2012. Combining a Bayesian nonparametric method with a hierarchical framework to estimate individual and temporal variation in growth. *Ecol. Model.*, *247*, 125–134.

Kanno, Y, J.C. Vokoun, K. Holsinger, and B. H. Letcher, 2012, Estimating size-specific brook trout abundance in continuously-sampled headwater streams using Bayesian mixed models with zero-inflation and over-dispersion, Ecol Freshw Fish, 21: 404-419, 10.1111/j.1600-0633.2012.00560.x

Kanno, Y, J.C. Vokoun, and B. H. Letcher, 2011. Fine-scale population structure and riverscape genetics of brook trout (*Salvelinus fontinalis*) distributed along headwater channel networks, Mol. Ecol. doi: 10.1111/j.1365-294X.2011.05210.x

Kanno, Y, J.C. Vokoun, and B. H. Letcher, 2011. Sibship reconstruction for inferring mating systems and effective population size in headwater brook trout (*Salvelinus fontinalis*) populations, Cons. Genetics. 12: 619-628. DOI 10.1007/s10592-010-0166-9

Nislow, K.H., M. Hudy, and Letcher, B.H., 2011, Variation in local abundance and species richness of stream fishes in relation to dispersal barriers: implications for management and conservation. Freshw. Ecol. 56, 2135-2144.

Papers submitted

Letcher, B.H., Schueller, P., Bassar, R., Nislow, K.H., Coombs, J.A., Sakrejda, K, Morrissey, M., Sigourney, S., Whiteley, A.R., O'Donnell, M. , Dubreuil, T., Robust estimates of environmental effects on population vital rates: an integrated capture-recapture model of seasonal brook trout growth, survival and movement in a stream network, Journal of Animal Ecology

Bassar, R., Letcher, B.H., Nislow, K.H., and Whiteley, A.R., Seasonal change in climate outpaces compensatory density-dependence in eastern brook trout, Ecology Letters

Kanno,Y., Letcher, B.H., Rosner, A.L., O'Neal, K.P., and Nislow, K.H., Hierarchical analysis of environmental factors affecting brook trout occurrence in headwater streams, Transactions of the American Fisheries Society

Overarching issues

- Local agencies don't always see the value in contributing to regional efforts
  - Many data requests from researchers and others
  - Many regional databases based on requests
    - Inconsistent and incomplete
  - Long lag times between request and results

- Multiple models based on inconsistent databases
  - Hard to identify useful models
  - Hard to compare models

Project-specific issues

- Need consistent regional data
  - Temperature data – NorEast?
  - Flow data – USGS gages, need more headwaters
  - Fish data – NA
  - High resolution catchments – NHD+ is inconsistent
- Importance of a dynamic process
  - New data every year
  - Get model improvement with new years and new locations
    - Regional models can actually improve state-specific models
  - Can we create a system to easily incorporate new data, provide a consistent regional database, and update models that states and others will use?
- Focus on brook trout
  - Models for multiple species could be very useful

Current related projects

- Structured decision making for management of headwater streams, NECSC. coPI with Evan Grant.
  - 2 year Post-doc (Dan Hocking): occupancy modeling
  - 2 year Post-doc (Rachel Katz): structured decision making
- Extreme event modeling, USGS Hurricane Sandy funding. PI.
  - 2 year Post-doc (Evan Childress): extreme event modeling
  - 2 year ¼ time Post-doc (Jeff Walker): DSS tool development
  - 3 year PhD student (Annalise Blum): hydrologic modeling
- Road-Stream Crossing Assessment for Climate Resilience and Aquatic Connectivity in the Sandy-Impacted Northeastern US, UMass Hurricane Sandy funding, coPI with Keith Nislow, Rick Palmer and Scott Jackson.
  - 1 year post-doc (TBD): Fragmentation effects

Potential extensions of existing work

- 1) Multispecies modeling
- 2) Model integration with data/management/policy
- 3) Others

Potential extensions of existing work

- 1) Multispecies modeling
  - Species-specific or community composition management
  - Invasive species effects
  - Need regional databases
    - Temperature, fish
  - Include migratory fish?
  - Existing post-docs can do modeling
    - Need database development
    - Make updatable?

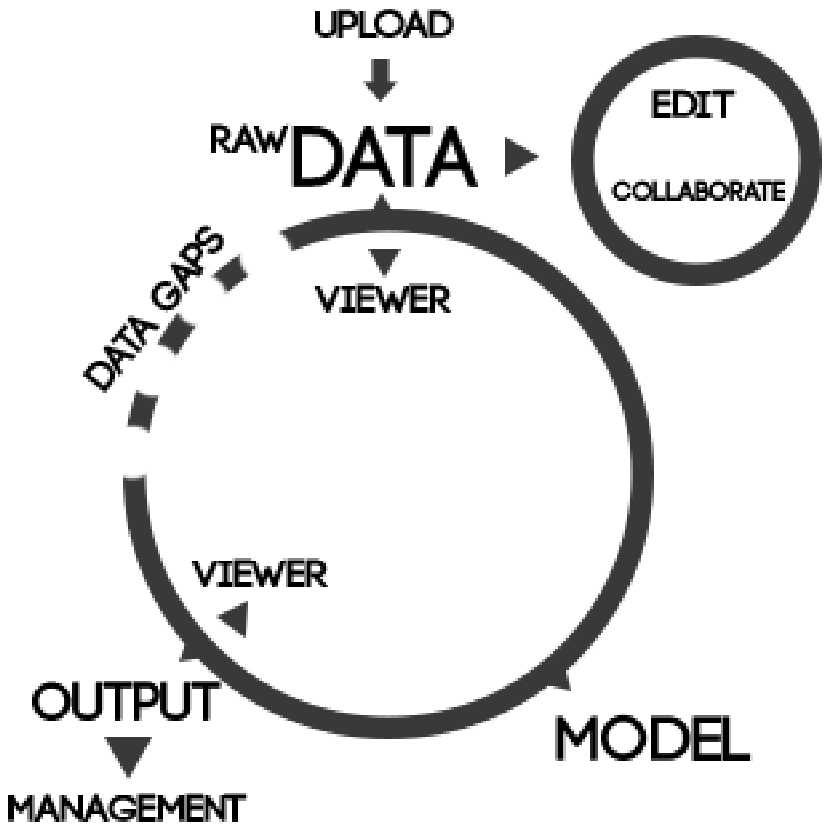
Example species:

Slimy Sculpin, *Cottus cognatus*
Fall fish, *Semotilus corporalis*
Brown trout, *Salmo trutta*
White sucker, *Catostomus commersonii*
Blacknose dace, *Rhinichthys atratulus*
Cutlip Minnow, *Exoglossum maxillingua*
Smallmouth Bass, *Micropterus dolomieu*
Rock Bass, *Ambloplites rupestris*
Brown Bullhead, *Ameiurus nebulosus*
Redbreast Sunfish, *Lepomis auritus*
Yellow Bullhead, *A. natalis*

Potential extensions of existing work

➔ 2) Model integration with management/policy

- Breeding bird survey as model
- System to integrate and unify
  - Data
    - Temp, flow, fish, other species
    - 'Rawest' data possible
  - Database
    - Flexible format
  - Models
    - Occupancy, abundance
    - Coordinate modeling efforts
      - e.g. Allow weighting of alternate models
  - Management
    - Dynamically-updated maps
    - Easy visualization
    - Scenario testing
- Could be applied easily to other systems
  - Culverts, Wetlands surveys, etc.



Potential extensions of existing work

- Personnel – Complete plan

Database development	52 weeks	$80K
Decision support	104 weeks	$172K
Programmer	39 weeks	$43K
Total		$296K

- Personnel – Partial plan

Database development	26 weeks	$40K
Decision support	52 weeks	$86K
Programmer	26 weeks	$29K
Total		$155K